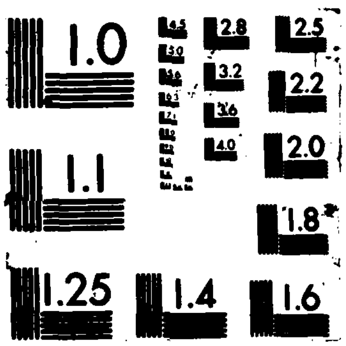
AD-A186 286 SHOULD NEURAL NETWORKS BE STUDIED TO ASSIST THE DECISION FUNCTIONS OF TACTICAL ACTION OFFICERS?(U) NAVAL POSTGRADUATE SCHOOL MONTEREY CA R W BRINKLEY 1/1

UNCLASSIFIED SEP 87 F/G 12/9 NL


1.0
2.8
2.5
3.2
2.2
3.6
4.0
2.0
1.1
1.8
1.25
1.4
1.6

NAVAL POSTGRADUATE SCHOOL

Monterey, California

THESIS

SHOULD NEURAL NETWORKS BE STUDIED TO ASSIST THE DECISION FUNCTIONS OF TACTICAL ACTION OFFICERS?

by

Ronald W. Brinkley

September 1987

Thesis Advisor: Carl R. Jones

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE

AD-A185 182

REPORT DOCUMENTATION PAGE

1a REPORT SECURITY CLASSIFICATION Unclassified	1b RESTRICTIVE MARKINGS
2a SECURITY CLASSIFICATION AUTHORITY	3 DISTRIBUTION/AVAILABILITY OF REPORT Approved for public release; Distribution is unlimited
2b DECLASSIFICATION/DOWNGRADING SCHEDULE	
4 PERFORMING ORGANIZATION REPORT NUMBER(S)	5 MONITORING ORGANIZATION REPORT NUMBER(S)
6a NAME OF PERFORMING ORGANIZATION Naval Postgraduate School 6b OFFICE SYMBOL (If applicable) Code 54	7a NAME OF MONITORING ORGANIZATION Naval Postgraduate School
6c ADDRESS (City, State, and ZIP Code) Monterey, California 93943-5000	7b ADDRESS (City, State, and ZIP Code) Monterey, California 93943-5000
8a NAME OF FUNDING/SPONSORING ORGANIZATION 8b OFFICE SYMBOL (If applicable)	9 PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER
8c ADDRESS (City, State, and ZIP Code)	10 SOURCE OF FUNDING NUMBERS PROGRAM ELEMENT NO / PROJECT NO / TASK NO / WORK UNIT ACCESSION NO

11 TITLE (Include Security Classification)
SHOULD NEURAL NETWORKS BE STUDIED TO ASSIST THE DECISION FUNCTIONS OF TACTICAL ACTION OFFICERS? (u)

12 PERSONAL AUTHOR(S)
Brinkley, Ronald W.

13a TYPE OF REPORT	13b TIME COVERED	14 DATE OF REPORT (Year, Month, Day)	15 PAGE COUNT
Master's Thesis	FROM ____ TO ____	1987 September	53

16 SUPPLEMENTARY NOTATION

17 COSATI CODES			18 SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
FIELD	GROUP	SUB-GROUP	Neural Networks, Neural Nets, Tactical Action Officer(TAO), Decision Functions

19 ABSTRACT (Continue on reverse if necessary and identify by block number)

The use of Artifical Intelligence(AI) such as expert systems and neurral networks could be instrumental in providing multi-level, real-time decision support assistance to the Tactical Action Officer (TAO). This paper examines the TAO concept and discusses some of its problems. Expert systems and neural networks are addressed concerning what they are along with an elementary explanation of how they work. Synopses of their capabilities and limitations are discussed in relation to specific elements of the TAO milieu. The final portion of the paper proposes a logical structure for a Comprehensive TAO Assistance System which would employ the AI technologies discussed.

20 DISTRIBUTION/AVAILABILITY OF ABSTRACT ☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT ☐ DTIC USERS	21 ABSTRACT SECURITY CLASSIFICATION Unclassified
22a NAME OF RESPONSIBLE INDIVIDUAL Prof. Carl R. Jones	22b TELEPHONE (Include Area Code) (408) 646-2767 22c OFFICE SYMBOL Code 54Js

DD FORM 1473, 84 MAR — 83 APR edition may be used until exhausted. All other editions are obsolete

SECURITY CLASSIFICATION OF THIS PAGE
UNCLASSIFIED

A-1

Approved for public release; distribution is unlimited.

Should Neural Networks be Studied to Assist the Decision Functions of Tactical Action Officers?

by

Ronald W. Brinkley
Lieutenant Commander, United States Navy
B.S., United States Naval Academy, 1977

Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN INFORMATION SYSTEMS

from the

NAVAL POSTGRADUATE SCHOOL
September 1987

Author: Ronald W. Brinkley

Approved by: Carl R. Jones, Thesis Advisor

Howard Venezia, Second Reader

Willis R. Greer, Jr., Chairman,
Department of Administrative Science

James M. Fremgen,
Acting Dean of Information and Policy Sciences

ABSTRACT

The use of Artificial Intelligence (AI) such as expert systems and neural networks could be instrumental in providing multi-level, real-time decision support assistance to the Tactical Action Officer (TAO). This paper examines the TAO concept and discusses some of its problems. Expert systems and neural networks are addressed concerning what they are along with an elementary explanation of how they work. Synopses of their capabilities and limitations are discussed in relation to specific elements of the TAO milieu. The final portion of the paper proposes a logical structure for a Comprehensive TAO Assistance System which would employ the AI technologies discussed.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

I. INTRODUCTION

A. PROBLEM DEFINITION

The Tactical Action Officer (TAO) is tasked with directing the tactical employment of his ship during the period of his watch [Ref. 1: p. 4-16]. Even though the watchstation of TAO was created primarily to provide quick reaction defense of Naval vessels during periods of hostilities [Ref. 2: p. 56], the TAO's charge can cover the entire spectrum of tasks his ship may be directed to perform from independent steaming in peacetime to combat operations in a battle group [Ref. 1: p. 4-16].

It is known among naval circles that in directing tactical operations, the TAO must assess a plethora of information and make a multitude of decisions in directing the efforts of his ship to detect, classify, localize, track, and destroy the enemy. The body of knowledge he must consider includes already received and newly incoming facts and estimates dealing with the acoustic environment, weapons, procedures, orders of battle, rules of engagement, the political situation, and other factors which may affect his decisions. In war, the speed and accuracy with which he can assess information, reach decisions, and act upon them could mean the difference between victory or defeat.

The nature of modern warfare often requires information to be evaluated and correct decisions to be made in fractions of seconds. The short amount of time available to access and correctly assess information and the frequent absence of important information are often cited as reasons for incorrect tactical actions.

Decision aids for the TAO can be divided into 3 groups: 1) those that provide planning support or baseline information which is used before an operation such as naval warfare publications, intelligence reports, and instructions from higher authority; 2) those that assist in the detection and identification of contacts once an operation commences such as sensors and signal processors; and 3) those that help evaluate information and decide how best to continue an operation such as displays, Combat Information Center (CIC) procedures, and quick reaction computer systems. This author knows of no operational decision aid that combines all these groups into one entity that can provide real-time tactically viable assistance to the TAO.

B. EXECUTIVE SUMMARY

The use of Artificial Intelligence (AI) systems such as expert systems and neural networks could be instrumental in providing multi-level, real-time decision support assistance to the TAO. AI is a branch of computer science that consists of hardware and software that exhibit intelligent behavior. These systems can assist in the solving of ill-structured problems or even solve problems by themselves. [Ref. 3: p. 40]

Initial thoughts on the milieu encountered by the TAO indicate three areas where artificial intelligence could assist: data storage and rapid retrieval, data analysis and decision support. Rapid data retrieval is the ability to quickly access information from some data base. The author defines data analysis as the examination of information to aid tactical decision makers in reaching an assumption about enemy actions or intentions. Decision support is the use of computer-based technology to aid command authorities in decision making in semistructured or unstructured decision tasks [Ref. 4: p. 1]. Expert systems appear to have merit in recommending tactical actions to the TAO [Ref. 5: p. 13] and neural networks show promise in dealing with incomplete or fuzzy data [Ref. 6: p. 25]. A real-time decision support aid to the TAO using these new technologies should be pursued.

C. THESIS OBJECTIVES

This thesis will attempt to answer the following questions:

1. Can the execution of TAO responsibilities be improved with the assistance of Artificial Intelligence based systems, in particular, neural networks?
2. Is the current state of the art in neural network development sufficient to allow their near-term use in the tactical environment by a TAO?

The first phase of research will define the Tactical Action Officer concept and discuss some problem areas inherent with it. In the course of this section, a possible ASW scenario will be presented to illustrate the TAO's milieu. The next steps in the process will address expert systems and neural networks, covering what they are, give basic descriptions of their characteristics and an understanding of how they work. Synopses of their capabilities and limitations will also be discussed. The final portion of the paper will propose a structure for a Comprehensive TAO Assistance System (CTAS) which would employ the AI technologies discussed.

II. THE TAO CONCEPT

A. BACKGROUND

1. Definition

OPNAV Instruction 3120.32, the Standard Organization and Regulations Manual for Naval ships states that [Ref. 1: p. 4-16],

> The Tactical Action Officer is the representative of the Commanding Officer (CO) concerning the tactical employment and the defense of the unit. . . . The TAO is responsible for the safe and effective operation of the combat systems and for any other duties prescribed by the Commanding Officer.

The TAO has the authority to fight the ship using ship's weapons or other assets under ship's control when the tactical situation demands. He has the responsibility to defend his vessel and is accountable directly to the ship's Commanding Officer for his actions and decisions. [Ref. 5: pp. 15-16]

2. Need for TAOs

Current Soviet maritime warfare strategy and naval tactics call for mass coordinated missile attacks on the enemy naval force from air, surface and sub-surface platforms in a sophisticated EW environment [Ref. 2: p. 56]. Because reaction time to missile attack is measured in seconds, it is neither expected nor possible for the Commanding Officer to be in the ship's Combat Information Center (CIC) during every moment in which the ship faces possible danger. Accordingly, the position of TAO was created to defend the ship until the CO arrived in CIC and then assist him when he assumed the duties of fighting the ship [Ref. 2: p. 57]. Since the watch station was formally established by the Chief of Naval Operations in the 1970's [Ref. 2: p. 57], it is generally accepted that the responsibilities of the TAO have increased from merely defending the ship until the captain arrives, to actually handling the bulk of the tactical decision making with the CO directing his actions via the maxim "control by negation".

In May 1972, the CO of the USS STERETT (DLG 31) included in the report of his ship's engagement in Dong Hai Gulf the statement, "The Commanding Officer who tries to run a 'one man' show will lose his ship." [Ref. 2: p. 56]. It can be concluded that there is an acknowledged reliance on the abilities and role of the TAO.

3. TAO Qualifications

On most destroyer or frigate sized ships the TAO is a 'warfare qualified' Lieutenant or Lieutenant Commander with at least four years of fleet experience [Ref. 2: p. 57]. His basic knowledge should normally include the following [Ref. 5: pp. 15-16]:

* A background of knowledge and experience in Anti-Air Warfare (AAW), Anti-Submarine Warfare (ASW), Anti-Surface Warfare (ASUW), Amphibious Warfare (AMW), and Electronic Warfare (EW), including a detailed knowledge of his own ship's weapons and propulsion capabilities and limitations.
* A good knowledge of the characteristics, capabilities, and limitations of fighter, attack, ASW, EW and Airborne Early Warning (AEW) aircraft, their associated weapons systems and their means of employment.
* Familiarity with AAW, ASW, and EW sensors employed by his own ship and other units operating in the area.
* A familiarity with available intelligence on pertinent, potential enemy tactics and doctrines and substantial knowledge about the capabilities and limitations of enemy hardware resources; including platforms as well as Anti-Ship Cruise Missiles (ASCMs).
* Knowledge of the procedures utilized for Air Intercept Control (AIC) and for Combat Air Patrol (CAP)/missile coordination.

B. PROBLEM AREAS

1. Domain Complexity

The range of stimuli to which the TAO must respond in identifying and assessing the threat to his ship is so large that it is very unlikely he would be able to consider all possibilities [Ref. 5: p. 12] without some means of paring the list. His range of responses to counter the threat, which is governed by rules of engagement [Ref. 7: p. 12], can vary from avoiding action to engaging and destroying the enemy. In choosing his course of action, the TAO must consider many facets including his own as well as enemy capabilities. In that process he must estimate a probability of success either explicitly or implicitly when selecting among his developed alternatives. The basic knowledge with which the TAO must be familiar (shown in subsection 3 above) gives an idea of the complex arena in which he must function.

2. Temporal Pressure

It is generally known in military circles that the speed and sophistication of weapon systems have increased dramatically in the years since World War II. Where submarines of the 1940's had maximum speeds of less than 20 knots and fired torpedoes from a few hundred yards away, modern nuclear subs have maximum speeds well in excess of 25 knots and can launch sea-skimming missiles from far beyond the visual horizon. Persons familiar with the passive ASW problem would agree that although the early phases of a prosecution can usually be measured in minutes or even hours, split second decision making is often required to ensure a successful mission. This is especially true in defending against ASCMs launched from a submarine at close range.

It is logical to assume that the time it takes to place own-ship systems in operation plays a part in the time available for the TAO to react to a given situation. For many reasons it may be neither possible nor desireable to keep systems energized and fully ready at all times while at sea. Even if the weapon launcher is energized and loaded, firing parameters may have to be entered and weapon time of travel to the target must also be factored-in which further compacts the time available for the TAO to reach a decision on how best to defend his ship.

3. Information Overload and Accuracy

Table 1 lists but a sample of topics which can enter into the Tactical Action Officer's decisions. The heading *Outside World* shows external factors over which the TAO has very little if any control. They essentially create a cause and effect relationship to which the TAO can only react. *Ship Environment* shows several items in which the TAO may have control over some aspects. This represents his immediate surroundings. *Kernel Factors* lists constraints from higher authority. These are *given* values which govern the realm of operation within which all actions must be contained. [Ref. 5: pp. 28-29]

TABLE 1
ENVIRONMENTAL FACTORS TABLE

- *Outside World*
  * Mission
    - Offensive
    - Defensive
  * Anticipated Threat
    - Air
    - Surface
    - Submarine
    - Mine
  * Political Situation
    - World
    - Local
  * Enemy Actions
  * Actions of Friendly or Neutral Forces
  * Tactics
    - Friendly
    - Enemy
  * Intelligence Inputs
    - Off-ship
    - Ship-generated
  * Proximity to
    - Land
    - Enemy
    - Friendly Forces
    - Neutral Forces
    - Commercial Shipping
  * Meteorological Conditions
  * Bathylogical Conditions

TABLE 1

ENVIRONMENTAL FACTORS TABLE (CONT'D.)

- *Ship Environment*
  - * Engineering Status
    - Engines On-Line
    - Auxiliary Systems in Operation
    - Fuel Available/Consumption Rate
  - * Weapon Status
    - Loaded/Armed
    - Firing Parameters Set
    - ECCM Fixes Set
  - * Watch Condition of Readiness
    - General Quarters
    - Condition III
    - Condition IIAS
  - * Material Condition of Readiness
  - * Sensor Status
    - Operating
    - Stand-by
    - ECCM Measures Available/In use
  - * Crew Readiness
    - Level of Training
    - Amount of Fatigue
- *Kernel Factors*
  - * Rules of Engagement
  - * OTC Policy
  - * Command Policy

Environmental factors can change at any time and may indeed change many times during the course of an operation [Ref. 5: pp. 28-29]. All of the information accessable to the TAO must be carefully sorted to determine relevance and then applied to decisions concerning its accuracy and potential effect on the overall tactical situation within the time available.

A review of the curriculum taught to TAOs in courses ashore drives home the fact that a vast amount of knowledge must be learned. The timely recollection and consideration of relevant information is what makes the job of the TAO truly difficult [Ref. 7: p. 12]. Even though much of the required knowledge is available to the TAO in written form onboard ship, there is seldom sufficient time to locate a publication and read pertinent passages. Consequently, the TAO must rely on his ability to memorize and recall data which brings forth the question of "how accurate is his memory?".

4. TAO Training

a. Initial Training

'Growing' a Tactical Action Officer is a process that takes several years. The training of a TAO commences when an officer begins the steps to be designated 'warfare qualified'. For surface warfare officers this entails attending the Surface Warfare Officer's School Basic Course (SWOS Basic) upon entry into the community as a junior officer. There, the officer receives introductory level information on seamanship, warfare areas, and combat operations. The course of instruction includes more than 200 classroom hours in combat systems and tactics. [Ref. 8: p. 25]

Upon completing SWOS Basic the officer has an initial sea tour of from 2-3 years in which he applies and thus reinforces the subject matter learned in school [Ref. 8: p. 25]. The author believes ship type and employment play key roles in an officer's development to become a TAO. Hands-on training and actual observation can be important in learning the complex weapon systems of today. Because certain systems are only on certain ships and are employed only at specific times, some young officers may never get the hands-on weapons familiarity the initial sea tour should provide. Although lack of personal exposure is an impediment which can be overcome, it could put an officer at a disadvantage against his peers who have had the opportunity to observe systems firsthand shortly after learning about them in school.

The writer also feels the employment of the ship plays a factor in the tactical development of a junior officer. A ship that is in long term overhaul tends to be more concerned with equipment repair and replacement than training in tactical systems and doctrine. Whereas a ship that deploys to the 'hot spots' of the world such as the Eastern Mediterranean or Persian Gulf, will be at increased conditions of readiness that are more than just drill. In a ship so deployed, weapons and sensors are more apt to be operated in combat ready modes with all officers exercising their tactical thought processes. Comprehensive shipboard training programs and attendance at TAO school may ease this uneveness in exposure caused by ship employment but there is still no substitute for experience.

Usually before a surface warfare officer commences his first department head tour, he has the opportunity to attend TAO School either in the Surface Warfare Officer's School Department Head Course or at one of the Fleet Combat Training Centers [Ref. 8: p. 25]. TAO School consists of 6 weeks of instruction covering the following major areas [Ref. 8: p. 26]:

1) Administration, Orientation and Testing
2) Threat Detection, Display and Reporting
3) Threat Identification and Assessment
4) Threat Destruction/Neutralization

Trainers and mock-ups augment classroom time to enhance the learning process. [Ref. 8: p. 26]

b. Follow-on Training

It has been the author's experience that follow-on training is sporadic and essentially left up to the efforts of the officer and vicissitudes of ship schedules. Tactical training after TAO school usually comes via the following methods: 1) Tactical discussions with other officers, 2) Static wargames known as 'tacsits', 3) Computerized simulations and wargames (i.e. NAVTAG), 4) Shore-based trainers, 5) Pier-side trainers, 6) Fleet exercises, and 7) Professional readings and briefings. The frequency with which any of these occurs is a function of ship scheduling, the availability of training funds and the emphasis an officer and his command place on warfare proficiency.

5. Personnel Turnover

Routine transfers are also a fact of life in the Navy. Unfortunately, these transfers result in loss of ship-specific knowledge and require retraining of each new TAO in the systems and peculiarities of each ship. [Ref. 5: p. 14]

C. TYPICAL ASW SCENARIO

The following passage illustrates the complex environment in which TAOs must function [Ref. 5: pp.18-19].

During a period of increasing tensions, a Carrier Battle Group (CVBG) has been ordered from the continental US to reinforce the CVBG already on station in the Mediterranean (Med). The dispatching of the second battle group has been termed a provocative act by the adversary government which further stated the "peace loving people of the world will resist this blatant imperialist move". The National Command Authority has reiterated to all Commanding Officers their right to self defense yet cautioned them to exercise restraint.

A ship already on duty in the Med has been ordered to conduct passive ASW barrier operations in the waters west of Portugal in support of the CVBG passage through the strait of Gibraltar. The battle group reaches the vicinity of the ship on patrol during a period of poor visibility and severe weather including high winds and heavy seas. The ship having been on station for several days with no enemy submarine detection receives intelligence information of an anti-ship missile firing enemy submarine near the patrol area. The submarine reported is nuclear powered and is believed to be of the type that can fire its missiles while submerged. The ship's sonar capabilities have been significantly degraded due to the high ambient noise from the heavy weather and normally poor sonic conditions of the operating area. Additionally, commercial shipping in the vicinity is also adding to the ambient noise level. The ship's crew is fatigued and efficiency is further degraded from motion sickness as a result of the extended patrol and severe weather.

The TAO is informed by a maritime patrol aircraft operating in support that a contact is held on its sonobuoy pattern which is generating noises corresponding to the type of submarine for which they are searching. The reported position puts the submarine just within its maximum missile firing range to the CVBG but well within its optimum attack prosecution range to the TAO's ship. No other ship or aircraft sensors corroborate contact. The TAO assesses that it would be highly unlikely for the submarine to have targeting quality information on the CVBG but quite possible that his ship may be targeted. He must make some decisions and make them quickly. What should he do?

This scenario is indicative of the demands placed on the TAO to quickly and accurately perceive and respond to numerous diverse and often contradictory stimuli in evaluating options and formulating decisions. The passage exemplifies the factors that require the TAO to exercise expert judgement despite stimuli that may mitigate that judgement.

III. EXPERT SYSTEMS

A. WHY CONSIDER EXPERT SYSTEMS?

Even though there is no substitute for the experience and training of the TAO, expert systems appear to hold promise in solving some of the problems mentioned in Chapter II. For example, the knowledge base of an expert system could store the baseline data and other considerations which may impact the TAO's thought processes [Ref. 9: p. 3]. This would mean less reliance on the TAO's memory and facilitate logical consideration of the consequences of alternatives selected via asking relevant questions in a logical order [Refs. 9,5: pp. 3,22]. Logic would indicate that an expert system would be helpful with the temporal pressure and information overload problem because a computer can process data and other decision elements at very high speed [Ref. 5: p. 12]. Proper programming would enable all pertinent factors to actually impact the decision process vice only considering those which the TAO happens to remember. Electronic data storage and retrieval could also assist in the verification of sensor data. Known parameters could be stored in memory and rapidly compared with received signals from ship sensors to aid in identification [Ref. 5: pp. 12-13]. The problem of personnel turnover would be lessened because the expert system would contain all required knowledge and ship-specific information thus easing the transfer of knowledge from one TAO to another. Even though training the TAO is still required, his ability to remain current would be facilitated through use of the expert system as a training tool. One more factor to consider is that computers do not get tired as people do. This eliminates fatigue as an inhibitor to proper TAO decision making.

B. DEFINITION OF EXPERT SYSTEMS

Professor Edward Feigenbaum of Stanford University, one of the pioneers in expert systems, defines an expert system as [Ref. 10: p. 1]:

> . . . an intelligent computer program that uses knowledge and inference procedures to solve problems that are difficult enough to require significant human expertise for their solution.

Because real-world tactical problems are complex, expert systems use heuristics to focus the domain to be searched [Ref. 5: p. 22]. Fiegenbaum and Feldman [Ref. 11: p. 6] define a heuristic as:

> . . . a rule of thumb, strategy, trick, simplification, or any other kind of device which drastically limits search for solutions in large problem spaces. . . . the payoff in using heuristics is greatly reduced search and, therefore, practicality.

The basic components of an expert system are a knowledge base and an inference engine. The knowledge base consists of facts, rules, and heuristics which embody the expert's knowledge while the inference engine consists of the strategies and controls which manipulate the knowledge base to determine a solution to a given problem [Ref. 12: p. 34].

Conventional programs differ from expert systems in that sequential computer programs use algorithms as their means for solving problems and expert systems use heuristics to search a knowledge base. Also, expert systems have a clear separation of data from the inference engine as opposed the adjacent storage of data and instructions in conventional programs. [Ref. 12: pp. 7-8]

In very basic terms, an expert system is a repository of knowledge of a specific domain and procedures for putting that knowledge to use [Ref. 5: p. 25].

For a more in-depth understanding of expert systems, the reader is invited to review any of the references on expert systems currently available such as: *Expert Systems: Artificial Intelligence in Business* by Paul Harmon and David King, *Expert System Technology: Development and Application* by Robert Keller or *Expert Systems: A Non-Programmer's Guide to Development and Applications* by Paul Siegel.

C. CAPABILITIES AND LIMITATIONS

Expert systems are good for applying a fixed set of logical rules dealing with related facts in a specific domain [Ref. 6: p. 25]. Such stipulations are applicable to many TAO functions but not necessarily to all. Particularly, expert systems fail when input data is incomplete or fuzzy [Ref. 13: p. 4]. Even so, Zivovic and Gostlow demonstrated the practical utility of expert systems in tactical applications with their separate prototypes to assist the TAO. However, both concluded that a major limitation of their systems was the fact that they could not respond in real-time [Refs. 5,7: pp. 51,46]. These limitations would imply that current prototypes are useful for training purposes but not actual tactical use. The author believes neural networks may hold the key to overcoming these limitations.

IV. NEURAL NETWORKS

A. WHAT ARE THEY?

Neural networks (also known as neural nets or parallel distributed processing) are essentially differential equations that emulate the structure and function of the brain at the neuron level. They describe the behavior of neurons and the interconnections among them. [Ref. 13: p. 4] Neurons can be thought of as very simple processors. In a rudimentary sense, the brain is a mass of tiny processors which are interconnected in a very densely parallel manner. These processors communicate among themselves through the transmission of electrical signals which either excite or inhibit connected processors that receive the signals. The 'state of activation' among a set of neurons is how information is represented and processed. [Ref. 6: p. 26]

Although both neural networks and expert systems are intelligent computer systems, there are significant differences between them. A primary difference is the level at which each perceives and understands data. Expert systems identify and execute higher-level processes and relationships whereas neural nets mimic biological processes and functions at the lowest levels of cognition. [Ref. 6: p. 25] For example, an expert system (ES) may contain the rule "If signal frequency is 50hz then the sound source is probably a propeller". Neural networks might represent individual words or letters in the above rule or perhaps even the intrinsic characteristics of the sonar signal itself. Representing information in this manner can require large numbers of neuron activations to denote a particular element or idea.

B. NEURAL NETWORK COMPONENTS

Eight structures or concepts are important in understanding how neural networks function. They are [Ref. 14: p. 46]:

- Processing Units
- State of Activation
- Output Function
- Pattern of Connectivity
- Propagation Rule
- Activation Rule
- Learning Rule
- Environment

1. Processing Units

Processing units (also called neurons, nodes or units) [Ref. 15: p. 2] are relatively simple entities, each doing a simple job [Ref. 14: p. 47]. Each node accepts multiple inputs and generates a single output [Ref. 15: p. 2] which in turn is transmitted to other nodes as inputs. The output of each unit is determined by a differential equation which describes how the signal evolves over time [Ref. 15: p. 2]. The set of neurons that are 'turned on' and the degree to which each neuron is turned on is how macro processing functions are accomplished. The activated set of nodes represents particular conceptual objects or abstract meanings over which meaningful patterns can be described. [Ref. 14: pp. 46-47]

2. State of Activation

According to David Rumelhardt, the *state of activation* is the "pattern of activation over the set of processing units". In conventional computers, information is represented by the number and sequence of ones and zeros, whereas in neural nets it is the pattern of processor activation that captures what the system is trying to represent. Although node values may be binary as in conventional digital processors, the activation values may be continuous or discrete over some range of values depending on what the system is intended to model. For example, node output values may be all real numbers between -1 and +1 or perhaps discrete values within some set of numbers such as $\{0,1,2,3,4,5,6,7,8,9\}$. [Ref. 14: p. 48]

3. Output Function

The *output function* determines the strength or value of the signal a processing unit sends to its neighbors. It is the means by which processing units interact. It can be described by a differential equation that uses the input signal received to determine the degree to which a node is energized. [Ref. 14: p. 48]

4. Pattern of Connectivity

The *pattern of connectivity* is the configuration in which units are physically or logically interconnected. It is this configuration that constitutes what the system knows and how it will respond to any specific input. [Ref. 14: p. 49]

5. Rule of Propagation

The *rule of propagation* takes the output values of 'upstream' nodes and combines them to produce a net input for each particular unit [Ref. 14: p. 51].

6. Activation Rule

The *activation rule* controls the affect incoming signals will have on the unit by taking into account the current state of system activation. It uses the existing state of the system and output from upstream nodes as input values in producing a new node output. [Ref. 14: p. 51] The value resulting from this process is what the node's output function actually receives for its input.

7. Learning Rule

The *learning rule* is how a neural net can change its own processing or knowledge structure by itself. It gives the network the ability to develop new connections among nodes and eliminate or modify the strengths of existing connections. Thus, the system has the ability to learn autonomously. [Ref. 14: p. 52]

8. Environment

The *environment* in which the system must operate must be represented in a form understandable to the network. Usually this is done as a time-varying stochastic function over the range of possible input patterns [Ref. 14: p. 53]. The specifics of how this is done is not germane to this level of discussion.

C. HOW THEY WORK

A neural net system is logically divided into 3 parts: input, hidden, and output nodes. Input nodes receive stimuli from sources external to the system. Hidden nodes only receive inputs from and transmit to other nodes. They are not "visible" outside the system and may be present in several layers. As the name would suggest, output nodes send their signals out of the neural network system. [Ref. 14: p. 48]

Each neuron, except input neurons, receives input signals from many other neurons. In addition to the different output values of each node, each connection between them (sometimes called a synapse) has a value, called a weight, which is either added to or multiplied with the output signal prior to being received by the connected node. If the incoming signal exceeds the threshold level which is determined by the node's output function, the neuron "fires", meaning it sends its output signal to its neighbors. [Ref. 6: p. 26]

The weights of the connections between some neurons are permanently set while others fluctuate with net activity. The manner of the interconnections determines how the net functions. [Ref. 6: p. 26]

Because information is represented distributively over the set of processors, the net's performance is not dependent on any single neuron. Therefore, if one neuron fails, the pattern may still be completed. Research has shown that neural nets continue to function with little or no degradation with up to 15% of the neurons inoperable [Ref. 6: pp. 24,26].

The following example is excerpted from the article "Computing With Neural Networks" found in the May 1987 issue of High Technology:

> . . . suppose that the letter *A* is represented by a 10-bit binary code of *1s* and *0s*. In a network, 10 input neurons might receive this data (one neuron per bit) and relay it over weighted connections to neurons in the next layer. Each neuron in this layer might be connected to four input neurons and be designed to fire a pulse if the sum of the signals it receives is 1 or more. Here the synaptic weights come into play. If all the weights between the input and second layer of neurons were 1, for example, a second-layer neuron would need only one of its four input neurons to have a bit with the value of 1. On the other hand, if the weights were all 0.5, then the second-layer input would not fire unless at least two of its input neurons were *1s*.
>
> Output signals from the second layer are passed over weighted synapses to a third layer, where the process of neuron activation and inhibition occurs yet again. This sequence can be repeated through a number of layers until the signals reach an output layer. The pattern of active and inactive neurons in this last layer is equated to the response: "This is the letter *A*. " A different string of 10 input bits would propagate through the network across a different pattern of connections, and would result in its own characteristic output pattern.

D. CAPABILITIES OF NEURAL NETWORKS

It is believed that neural network technology could have significant impact in the areas of sensor processing, knowledge processing, and machine/robotic control [Ref. 15: p. 3]. All of these uses have potential tactical applications to several aspects of the TAO's functions. Some specifics of neural net capabilities are summarized in the following paragraphs.

One of the most promising near term tactical uses for neural networks involves their ability to recognize patterns. This has direct applications in the area of sonar and radar signal processing in that programmed sonic, electromagnetic or electro-optical patterns could be quickly gleaned from a mass of background noise. This pattern recognition quality also gives neural nets the ability to 'discover' salient features among stored data and to extract knowledge from seemingly unrelated and large amounts of data. [Refs. 6,13: pp. 25, 4]

Associative recall is the ability obtain the correct inputs from a degraded version of input data [Ref. 6: p. 25]. With this ability, nets can deal with inexactitudes, contradictions, errors and missing bits of information [Ref. 13: p. 4]. Such a characteristic would be useful in an expert system which may not have all required items of information or a sensor that is experiencing jamming or environmental interference.

Neural nets have the ability to implement an instantaneous nearest neighbor classification function for extremely large sets of example patterns, whether spatial or spatiotemporal [Ref. 15: p. 3]. A tactical application using this characteristic could provide immediate identification or classification of received acoustic, electromagnetic or electro-optical signals.

The fact that neural nets can modify stored information in response to new inputs means the system can learn [Ref. 6: p. 24]. The greater the number of repetitions the stronger the learned response [Ref. 13: p. 4]. This trait might give a signal processor the ability to more easily maintain track on a passive signal or re-detect a signal that had been held over a period of time but was lost due to ambient noise or use of countermeasures.

Parallel distributed processing has the ability to recall memories even if some neurons fail. The fact that information is distributed among many processors means that there is gradual degradation with damage as opposed to catastrophic failure in conventional computers. Neural networks can still function with 10 to 15% of their neurons destroyed. [Ref. 6: p. 24] Such a trait is an obvious benefit in terms of the computer's maintainability and capability to sustain battle damage.

Neural networks have demonstrated the ability to recognize continuous speech [Ref. 16]. This would possibly reap dividends by giving operators the ability to issue verbal commands to the weapon systems they control.

Neural networks, when used to augment conventional computers, appear to have promise in solving problems which were previously considered impossible. A decision assistance system combining neural network and expert system technologies could greatly assist the TAO in the performance of his duties.

V. COMPREHENSIVE TAO ASSISTANCE SYSTEM (CTAS): A PROPOSAL

Thus far we have addressed the need for the Tactical Action Officer concept and discussed some of the problems with its implementation. We then briefly covered what expert systems and neural networks are along with some of their capabilities and limitations.

Can Expert System Help Train Tactical Action Officers: Some Experiences From an Early Prototype by Streten Zivovic and *A TAO Expert System Prototype* by Gareth A. Gostlow created and presented expert system prototypes for use by Tactical Action Officers. Yet, these prototypes had several shortcomings which rendered them ineffective for shipboard tactical use. If the capabilities of neural nets, addressed in Chapter IV of this paper, can actually be applied, then it seems logical to pursue research into building a Tactical Action Officer assistance system which would incorporate these AI technologies into a single tactically useful system. This chapter will present a logical model for such a computerized decision aiding system, which the author calls a Comprehensive Tactical Action Officer Assistance System (CTAS), that may help solve some of the problems in fully realizing the TAO concept.

A. CTAS MODEL

1. Concept

It is envisioned that CTAS would combine all Tactical Action Officer decision aids into one interrelated system. Its core would be expert systems and signal processors based upon neural network technology. It is believed that such a structure would achieve the characteristics necessary to provide real-time expert assistance to all parts of the tactical decision making process.

CTAS is an expansion of the NTDS and AEGIS Combat System concepts. It is the next step in the continuum of providing computerized support to tactical decision makers at sea. Key to the system is employing direct sensor input to neural net signal processors which in turn would provide input data to neural network knowledge processing modules or conventional expert systems. A computer system such as this could aid the TAO in all facets and phases of mission execution and ship defense.

What follows is a hierarchical presentation of relevant attributes which the author feels are important in constructing such a system. The letters next to each node indicate the relative importance of that capability (A-Important, B- Useful, C- Desireable). Several levels of decomposition are presented in Figures 5.1 through 5.11. Three vertical dots with an arrow beneath a module indicate that the structure of that module is the same as that to which the arrow is pointing. A greater level of decomposition precision than that shown will be required before actual design but the figures give a possible system breakdown.

2. **Explanation of Structure**

The CTAS breakdown presented is based on the author's perception of system requirements as a result of his experience in computers, his knowledge of ship systems, and his experience as a TAO. Other structures are certainly possible and may even be more appropriate. This is but a baseline from which to commence discussion.

TAO school teaches Tactical Action Officers to think of defensive problems in terms of the specific threat and the best counter to that threat. Consequently, the given CTAS functional decomposition mainly uses the below listed hierarchy.

- Forces (Friendly, Enemy, Third Party)
- Major Equipment Systems
- Warfare Areas
- Medium of Signal Transmission
- Method of Signal Transmission

The three main sub-modules shown in Figure 5.1 are derived from the groups of TAO aids defined in Chapter I and the curriculum areas taught at TAO school. They follow the author's perception of the TAO's approach to defensive tactical problems. Module 1 is a repository of knowledge from which all decisions are based, module 2 is for identifying and assessing threats to the ship and module 3 determines actions to defend the ship via threat destruction or neutralization. Although this paper espouses further research into tactical uses for neural networks, a completely neural system may not be feasible nor desireable. Therefore, this structure may facilitate easier implementation of a hybrid system utilizing both conventional and neural computer architectures. Full names for all modules can be found in Table 2 on page 31.

a. Module 1 - Repository of Information

The information module is an advanced idea of the 'paperless ship' espoused by VADM Metcalf [Ref. 17]. It is an on-line library of tactical information containing knowledge of friendly and enemy weapon system capabilities, limitations, procedures, tactics and characteristics (essentially, the information summarized on page 10). From this readily available source of knowledge, the TAO will be able to understand the threat and plan effective actions against it.

All information must be in a form usable by CTAS either by database call-up or preferably by incorporation into the system's knowledge processing functions. There must also be a version available for use directly by the TAO.

The repository of information module is divided by period of storage (i.e. Long Term or Short Term). That is to say, whether it is expected that the information will be required indefinitely or for less than a few days. This is done because it may have a bearing on the methods of storage and access.

(1) *Module 1.1 - Long Term Information.* This is data with an indefinite shelf life. It contains background information required for effective decision making.

(2) *Module 1.1.1 - Warfare Publication Library.* Information contained in Naval Warfare Publications, intelligence documents and unit commander general operational planning directives (OPGENS). It is initially divided by friendly, enemy and third party forces, and planning instructions from higher authority. These modules are further decomposed by warfare areas which in turn are divided by major functional or information groups as may be appropriate.

(3) *Module 1.1.2 - Signal Library.* This module contains information concerning electromagnetic, acoustic and electro-optical signals which may be found in a maritime environment. The existence of this data in neural form within this module will depend on whether the signal representations are better maintained in separate modules or incorporated within the netware of the sensor signal processors. As a minimum this module will contain the data in a form usable by the TAO.

Further decomposition of this module is by force grouping, the medium through which the signal travels and method of signal transmission.

(4) *Module 1.1.3 - Own-Ship Specific Information.* This is information peculiar to the particular ship in which the CTAS resides. Data such as turning diameter, acceleration tables, equipment deficiencies, active sensor radiation patterns, quietest engineering configuration and most economical speed. It is decomposed in terms of ship systems and subsystems. Further decomposition is determined by the specifics of the system concerned. Figure 5.6 shows one possible configuration.

(5) *Module 1.2 - Short Term Information.* This module contains information with a finite shelf life. Except for purposes of engagement reconstruction the utility of data contained here would normally be measured in minutes, hours or days. It is the same information which would normally be displayed for the TAO on status boards in CIC. This information is basically a summary of sensor data, equipment/system status, navigational position and other information which may be used in the immediate decision process. Decomposition below the major system level is dependent upon the specifics of that major system.

b. Module 2 - Threat Identification and Assessment

This node is essentially an expert system which looks at sensor data and information contained in module 1 to identify and assess the threat to the ship. Instrumental to this plan are neural net signal processors which would glean desired signals from environmental noise. They may also be able to identify or classify these signals by weapon, type of ship or perhaps even down to the hull number of the emanating platform. These signals would then be considered as inputs to the knowledge processing portion of the module to aid in contact identification and assessment as to threat. The knowledge processing capabilities of neural networks may prove useful here.

c. Module 3 - Threat Destruction/Neutralization

This module is a knowledge processing system which looks at the assessed threat and other information to recommend ship actions to counter it. It is decomposed by major functions.

(1) *Module 3.1 - Target Selection.* This component would be a knowledge processing system to determine the most imminent threat to the ship. It would make such a determination by taking into account current target actions and recent history of enemy tactics. It would require direct inputs from module 2 and incorporate the knowledge contained in module 1.

(2) *Module 3.2 - Weapon Selection.* This component would select the best weapon to counter the threat and feed firing parameters directly to the weapon system.

(3) *Module 3.3 - Ship Control Functions.* This component of the knowledge processing system would recommend ship control actions to optimize target prosecution. Items such as recommending the best aspect to minimize own-ship radar signature and most appropriate engineering configuration to maintain necessary systems yet give maximum reserve capacities.

(4) *Module 3.4 - Sensor Operation.* This component would recommend the most appropriate ECCM parameters to enter to ensure sensor operation given possible and actual enemy countermeasures.

B. WHY USE NEURAL NETWORKS

1. Existing Technology

Someone who is familiar with current computer technology could make a case for implementing CTAS completely with existing expert system and database capabilities, thus avoiding the risks involved in employing a new and untested field. The author acknowledges that indeed many, if not all, of the modules proposed in CTAS could be constructed with proven conventional computer technology. However, the characteristics of neural networks indicate that they have the potential to vastly improve present capabilities in tactical uses of computers.

2. Maintaining the Tactical Picture

It is generally known among surface warriors that maintaining an accurate tactical picture at sea using computers is very difficult because it changes rapidly and deals with imperfect knowledge. It can also be added that current technologies require significant manual intervention to circumvent these problems. The intrinsic characteristics of neural nets to rapidly assess information and deal with incomplete, erroneous or incorrect inputs augur well toward solving these issues.

3. Signal Processing and Interpretation

Sensor processing is basically a two part problem: transforming patterns to a useful form and recognizing patterns once they are in that usable form. Neural nets are adept at such functions and can deal with both spatial patterns (i.e. fixed power spectra, fixed images, ship silhouettes, written words) and spatiotemporal patterns (i.e. dynamic video, continuous speech, sonar, radar, doppler audio). The Grossberg/Mingolla Vision Processing Network and the Fukushima Neocognition model have already demonstrated the ability to handle these tasks. [Ref. 15: p. 3]

The ability of neural nets to instantaneously match patterns and distill information from seemingly unrelated masses of data, make them ideal candidates for passive sonar systems, electro-optical sensors and anti-jam circuits.

4. Data Storage and Retrieval

Dr. James A. Anderson, from the Department of Physiology at UCLA, suggests a memory storage model which could have neural network applications

[Ref. 18: p. 113]. Such a model, combined with the ability of neural nets to rapidly search and correlate information, could provide a suitable architecture for knowledge processing CTAS modules that may allow them to function within the time constraints of a tactical engagement.

5. Threat Assessment

In dealing with threats at sea, information is often missing, may be contradictory or even wrong. Conventional expert systems do not function well in such an environment, yet, neural networks do very well. The Anderson Knowledge Processing Neural Network, the Kosko Fuzzy Cognitive Map and the Carpenter-Grossberg Adaptive Resonance Network have already demonstrated that capability.

6. Summary

Neural networks may not be a panacea to solve all the problems concerning computer decision related assistance to the tactical decision maker but they do portend well. CTAS, built with neural network technology, has the potential to provide the TAO with real-time, multi-level decision assistance. The author suggests further study is merited.

C. DEVELOPMENT ISSUES

Several topics must be addressed in constructing computerized decision assistance systems for the TAO. Zivovic and Gostlow mentioned several of these concerns in the presentations of their TAO expert system prototypes. Other questions include: 1) What kind of trade-offs should be made between decision support system speed versus reliability? 2) What system configuration is sufficiently robust in terms of both its ability to operate with incomplete data and its ability to sustain battle damage? 3) What form should the man-machine interface take considering the high stress environment in which it will be used? 4) What neural net models are appropriate for what function(s)? and 5) How can classified data be made quickly accessible and still kept secure? Answers to these questions would be interesting topics for future study.

TABLE 2
MODULE TITLES

- Module 0 - CTAS
- Module 1 - Repository of Information
  * Module 1.1 - Long Term Information
  * Module 1.1.1 - Warfare Publication Library
  * Module 1.1.1.1 - US/Allied Information
  * Module 1.1.1.2 - Enemy Information
  * Module 1.1.1.2.1 - AAW
  * Module 1.1.1.2.2 - ASW
  * Module 1.1.1.2.3 - ASUW
  * Module 1.1.1.2.3.1 - Concepts and Doctrine
  * Module 1.1.1.2.3.2 - Weapons and Combat Systems
  * Module 1.1.1.2.3.3 - Tactics
  * Module 1.1.1.2.3.4 - Planning and Control
  * Module 1.1.1.2.4 - Strike Warfare
  * Module 1.1.1.2.5 - Electronic Warfare
  * Module 1.1.1.3 - Third Party Forces
  * Module 1.1.1.4 - Unit Commander Instructions
  * Module 1.1.2 - Signal Library
  * Module 1.1.2.1 - US/Allied Signals
  * Module 1.1.2.2 - Enemy Signals
  * Module 1.1.2.3 - Third Party Signals
  * Module 1.1.2.2.1 - Electromagnetic Signals
  * Module 1.1.2.2.2 - Acoustic Signals
  * Module 1.1.2.2.2.1 - Active
  * Module 1.1.2.2.2.2 - Passive
  * Module 1.1.2.2.3 - Electro-Optical Signals
  * Module 1.1.2.3 - Third Party Signals

TABLE 2
MODULE TITLES (CONT'D.)

* Module 1.1.3 - Own-Ship Specific Information
* Module 1.1.3.1 - Weapons Information
* Module 1.1.3.1.1 - Above Water Weapons
* Module 1.1.3.1.2 - Underwater Weapons
* Module 1.1.3.2 - Sensor Information
* Module 1.1.3.2.1 - Electromagnetic Sensors
* Module 1.1.3.2.1.1 - Active
* Module 1.1.3.2.1.2 - Passive
* Module 1.1.3.2.2 - Acoustic Sensors
* Module 1.1.3.2.3 - Electro-Optical Sensors
* Module 1.1.3.3 - Ancillary Equipment
* Module 1.1.3.4 - Engineering Information
* Module 1.1.3.4.1 - Main Systems
* Module 1.1.3.4.1.1 - Propulsion
* Module 1.1.3.4.1.2 - Generators
* Module 1.1.3.4.2 - Auxiliary Systems
* Module 1.2 - Short Term Information
* Module 1.2.1 - Weapon Information
* Module 1.2.1.1 - Above Water Weapons
* Module 1.2.1.2 - Underwater Weapons
* Module 1.2.2 - Sensor Information
* Module 1.2.2.1 - Electromagnetic Sensors
* Module 1.2.2.1.1 - Active EM Sensors
* Module 1.2.2.1.2 - Passive EM Sensors
* Module 1.2.2.2 - Acoustic Sensors
* Module 1.2.2.3 - Electro-Optical Sensors
* Module 1.2.3 - Countermeasures Equipment
* Module 1.2.4 - Navigational Information

TABLE 2
MODULE TITLES (CONT'D.)

* Module 1.2.4.1 - Ship Geographic Position
* Module 1.2.4.2 - Hydrographic Information
* Module 1.2.4.3 - Meteorological Information
* Module 1.2.5 - Engineering Information
* Module 1.2.5.1 - Auxiliary Systems
* Module 1.2.5.2 - Main Systems
* Module 1.2.5.2.1 - Propulsion Systems
* Module 1.2.5.2.2 - Generators
* Module 1.2.6 - Tactical Reports
* Module 1.2.6.1 - Anti Submarine Warfare Reports
* Module 1.2.6.2 - Anti Air Warfare
* Module 1.2.6.3 - Anti Surface Warfare
* Module 1.2.6.4 - Strike Warfare
* Module 1.2.7 - Ancillary Equipment
* Module 1.2.8 - Contact Information
* Module 1.2.8.1 - Submarine
* Module 1.2.8.2 - Aircraft
* Module 1.2.8.3 - Surface Vessels
* Module 1.2.8.4 - Unknown Electromagnetic/Acoustic Signals

- Module 2 - Threat Identification and Assessment
  * Module 2.1 - Electromagnetic Signal Processors
  * Module 2.2 - Acoustic Signal Processors
  * Module 2.2.1 - Active
  * Module 2.2.2 - Passive
  * Module 2.3 - Electro-Optic Signal Processors
- Module 3 - Threat Destruct
  * Module 3.1 - Target Selection

TABLE 2
MODULE TITLES (CONT'D.)

* Module 3.2 - Weapon Selection
* Module 3.3 - Ship Control Functions
* Module 3.4 - Sensor Operation

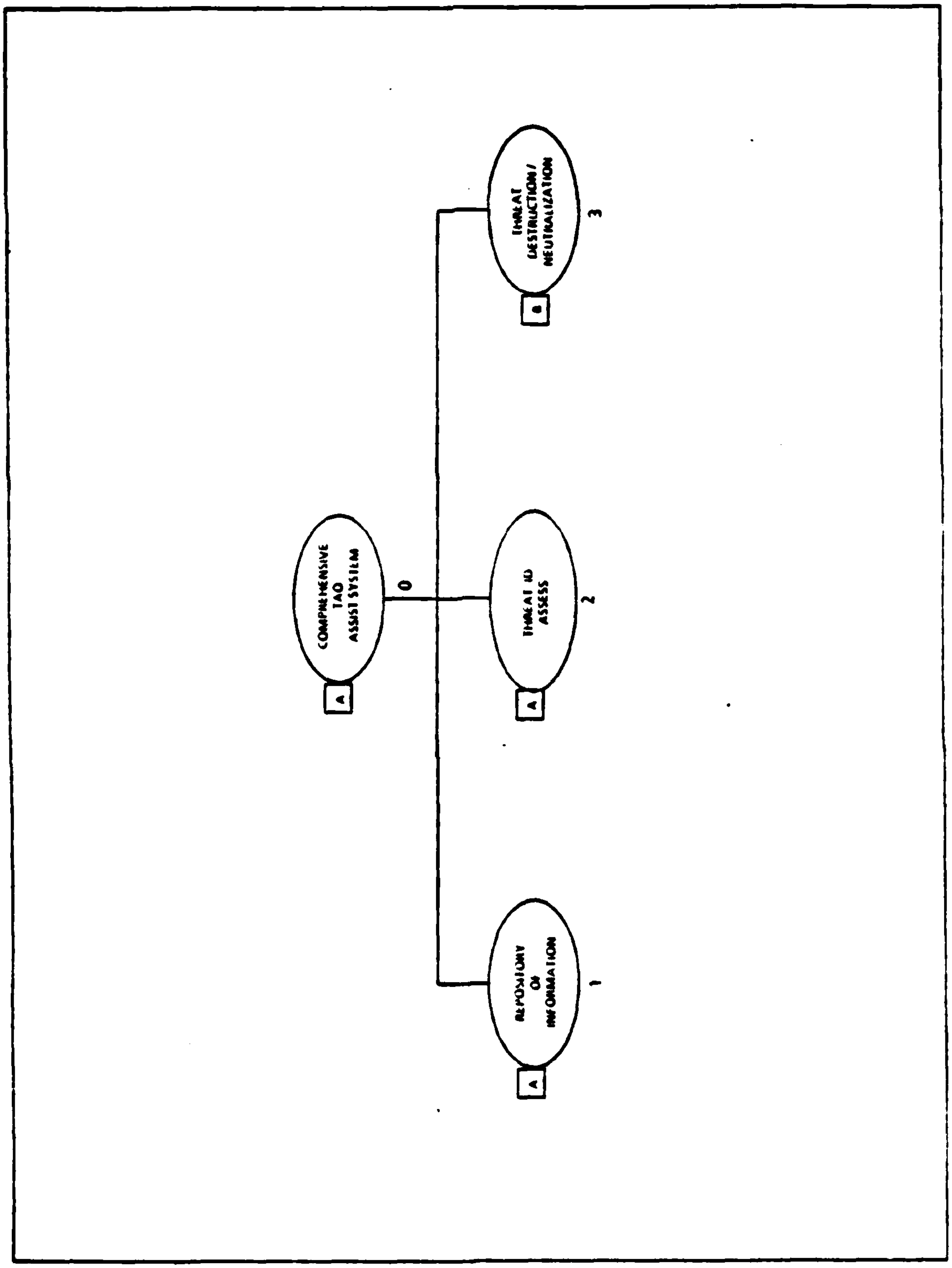


Figure 5.1 CTAS Level 0.

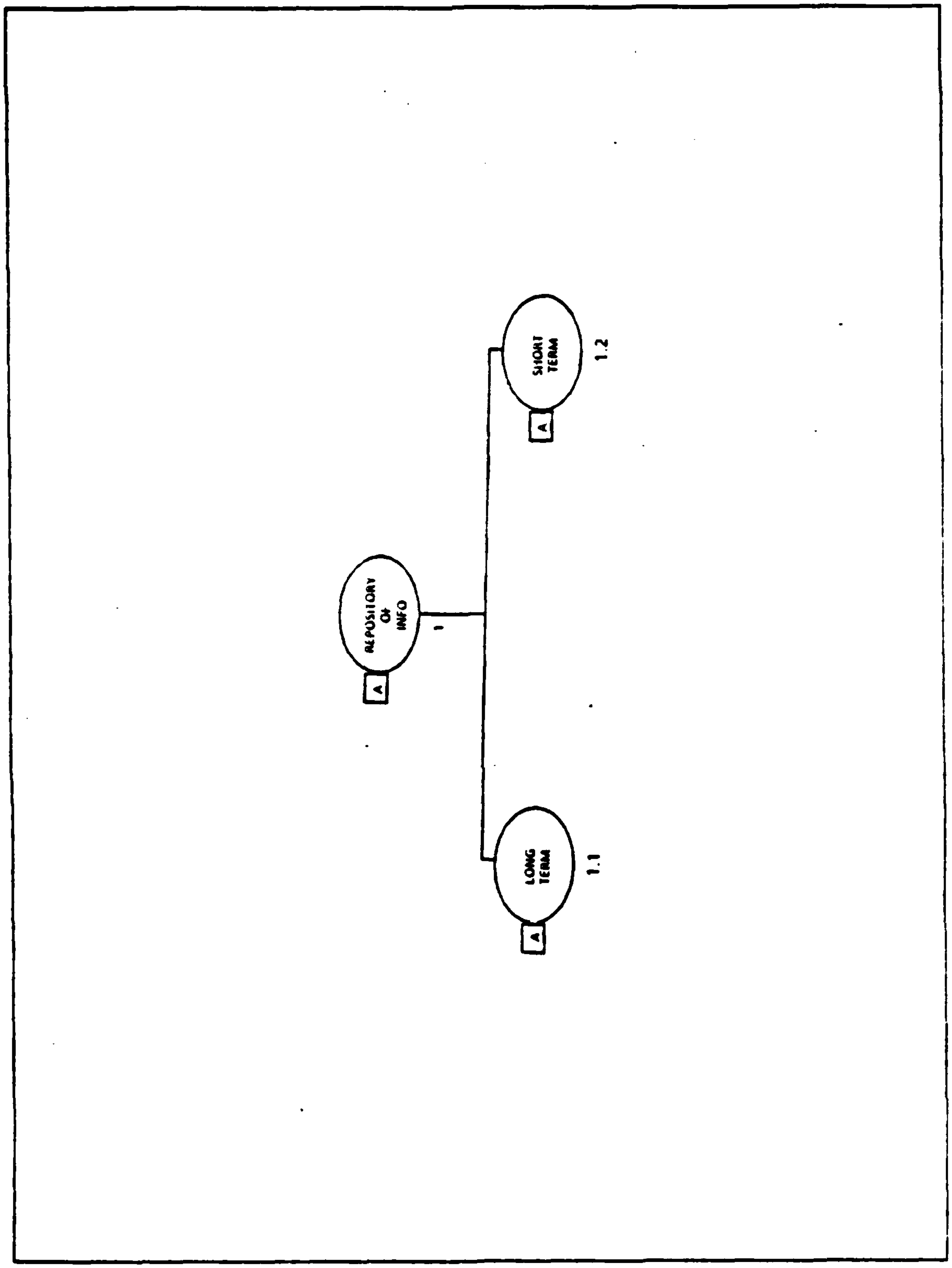


Figure 5.2   CTAS Level 1.

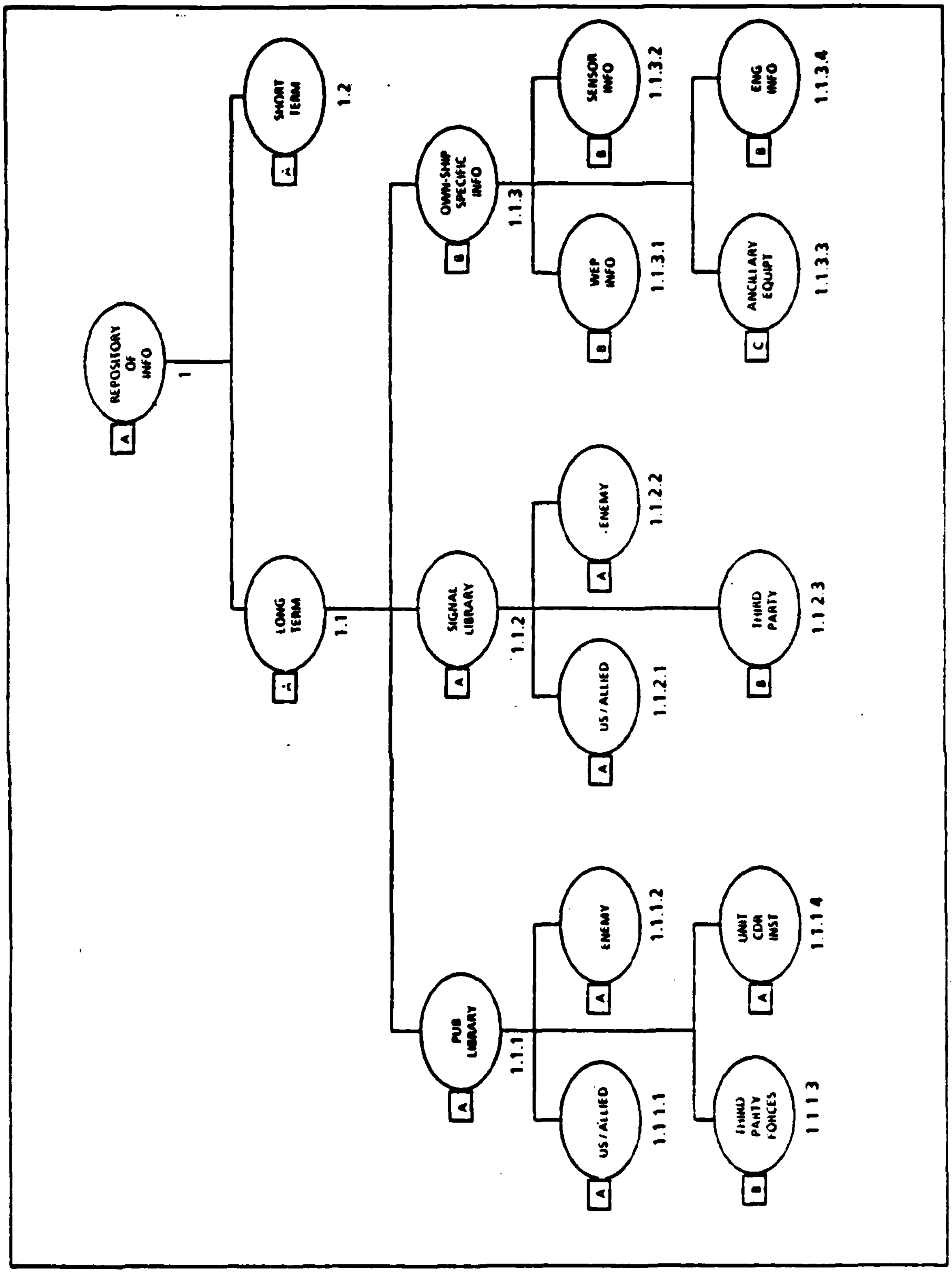


Figure 5.3 CTAS Level 1.1.

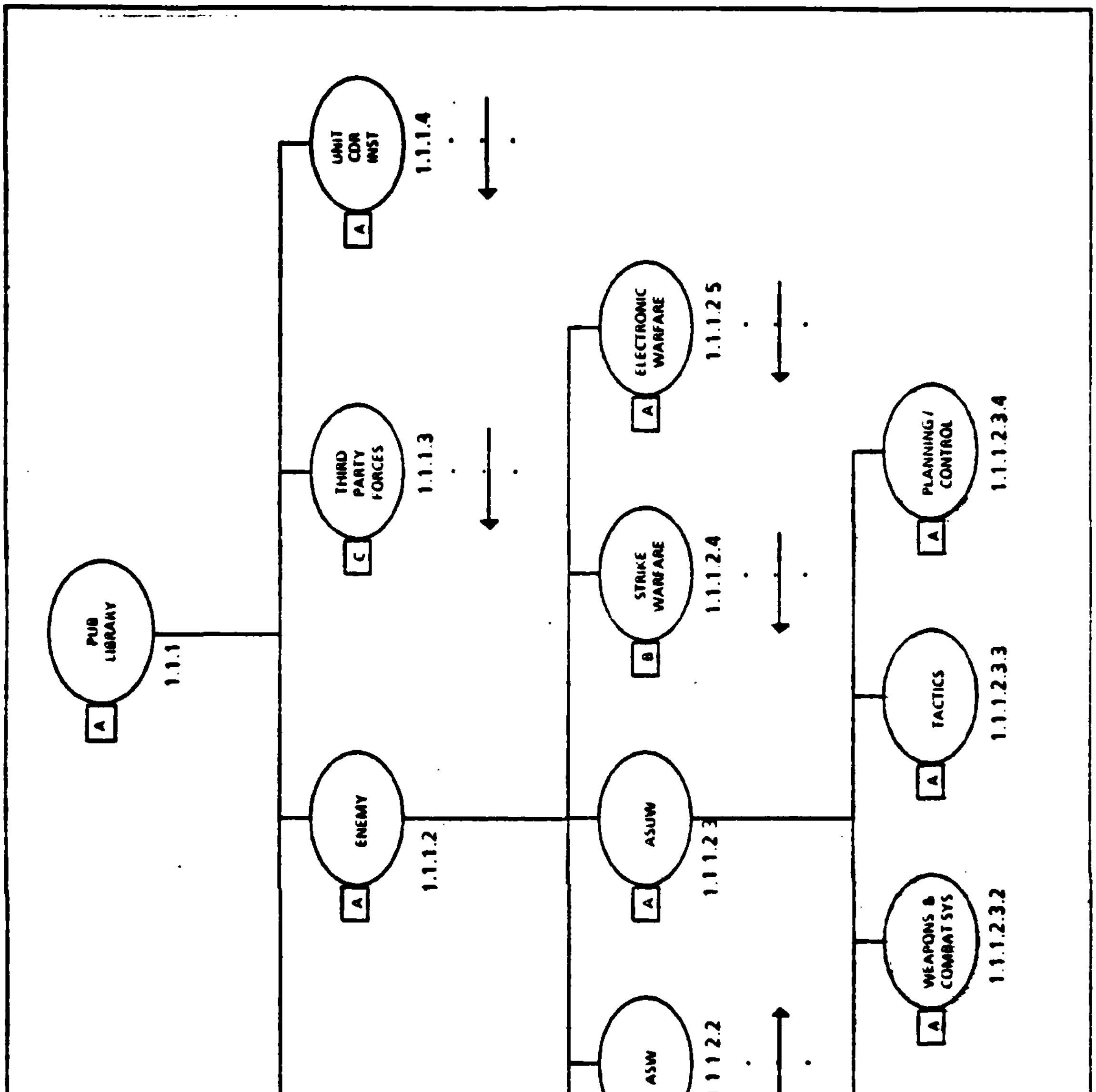


Figure 5.4 CTAS Level 1.1.1.

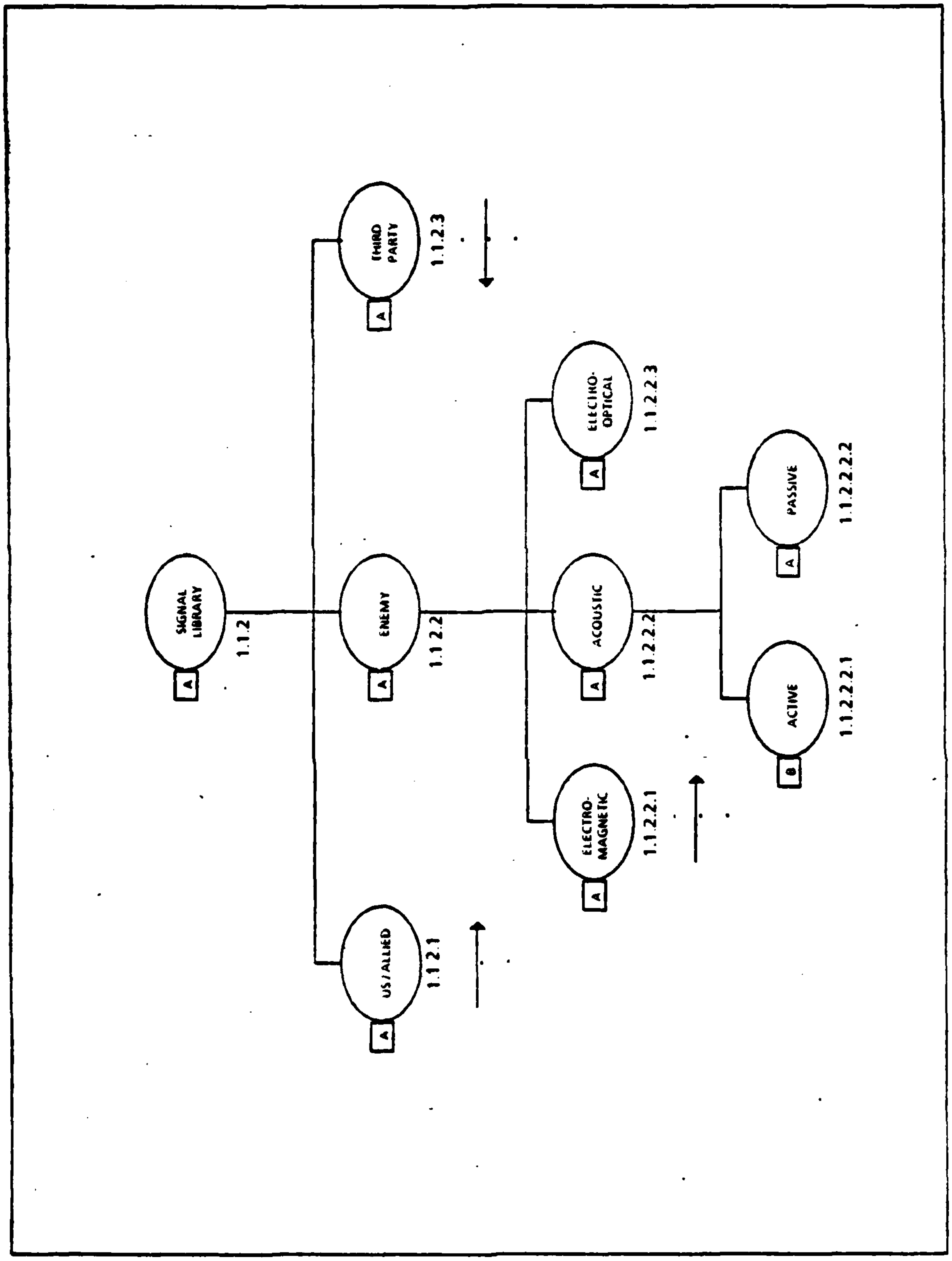


Figure 5.5 CTAS Level 1.1.2.

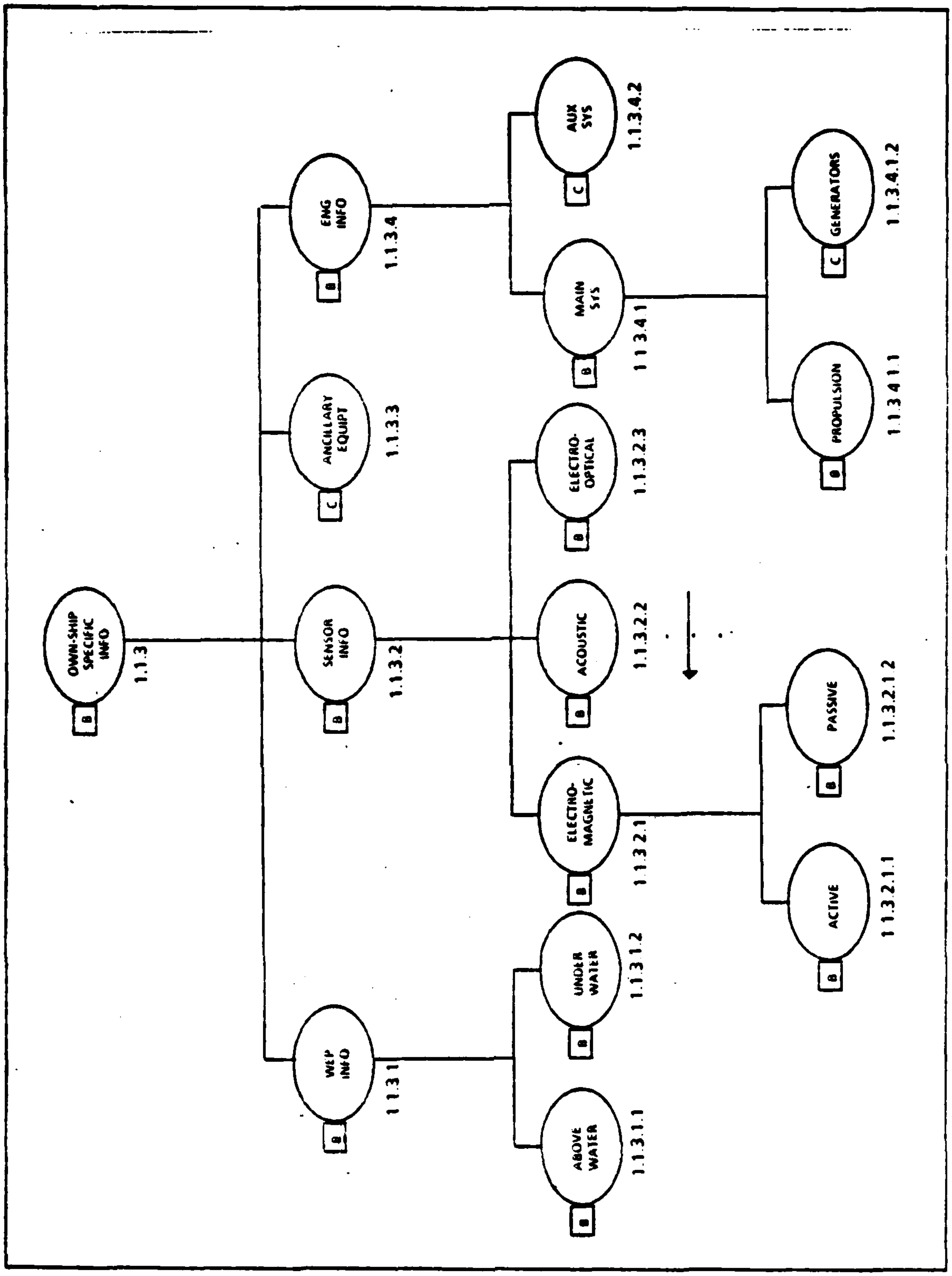


Figure 5.6 CTAS Level 1.1.3.

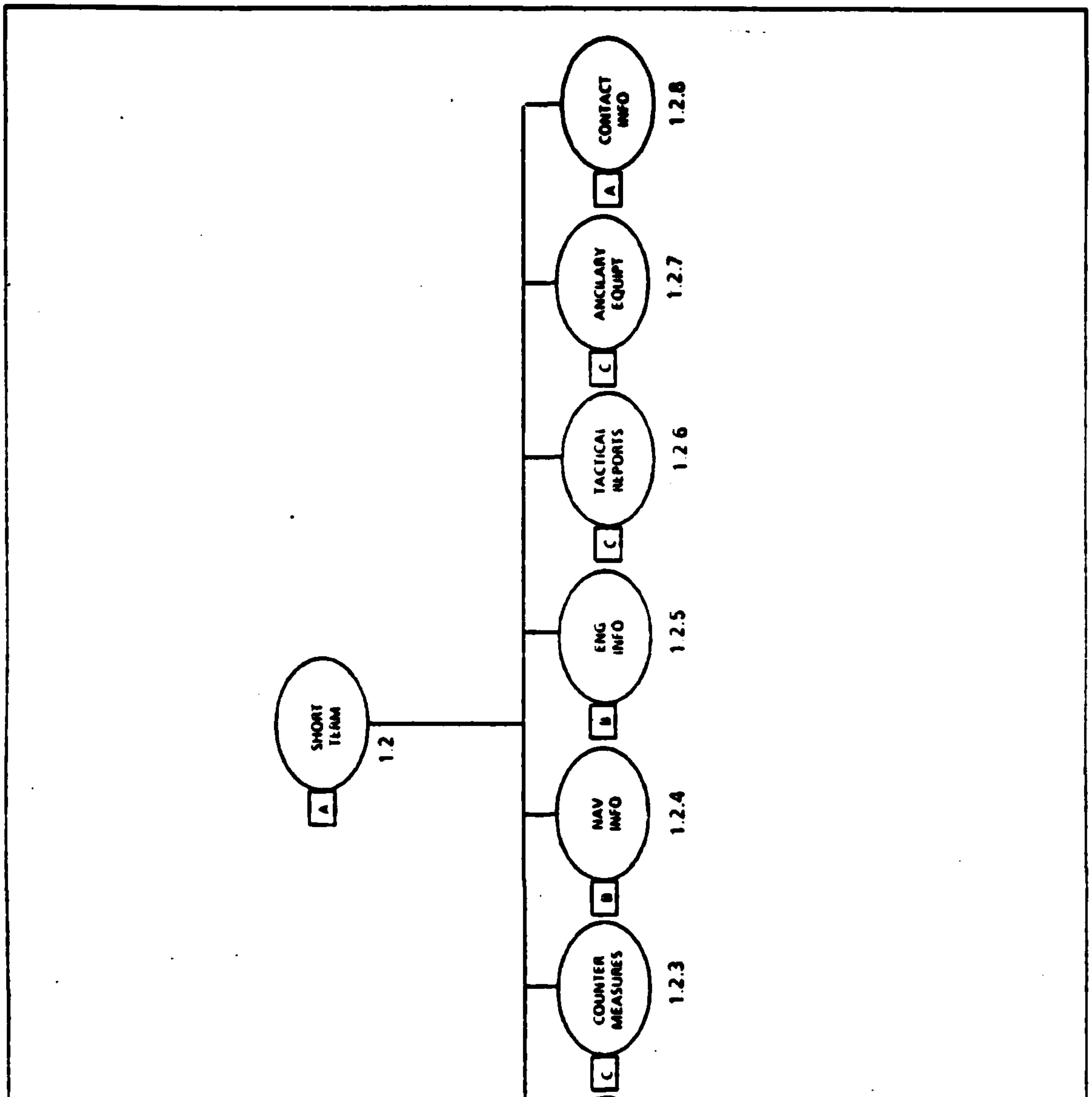


Figure 5.7 CTAS Level 1.2.

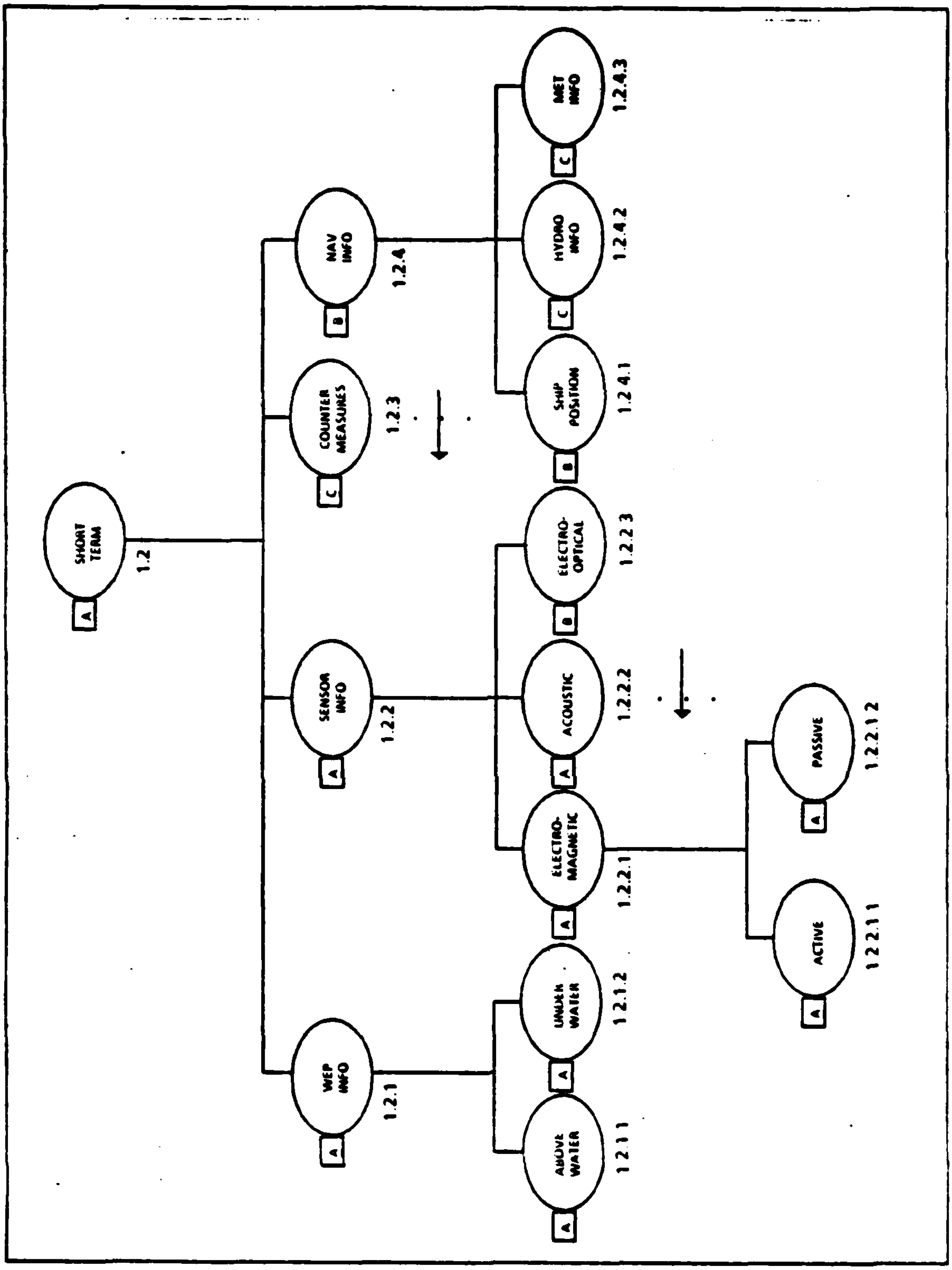


Figure 5.8 CTAS Levels 1.2.1 through 1.2.4.

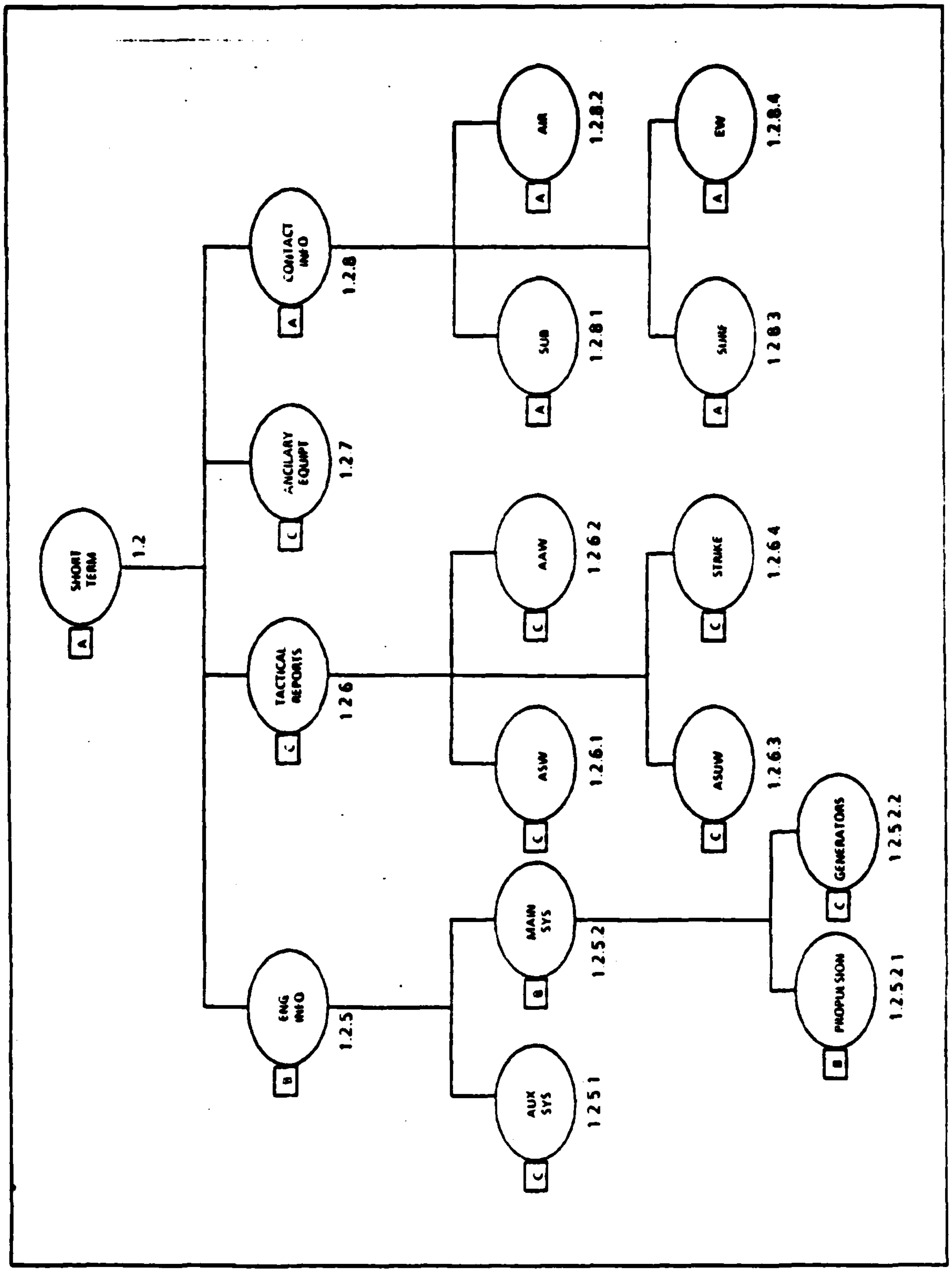


Figure 5.9 CTAS Levels 1.2.5 through 1.2.8.

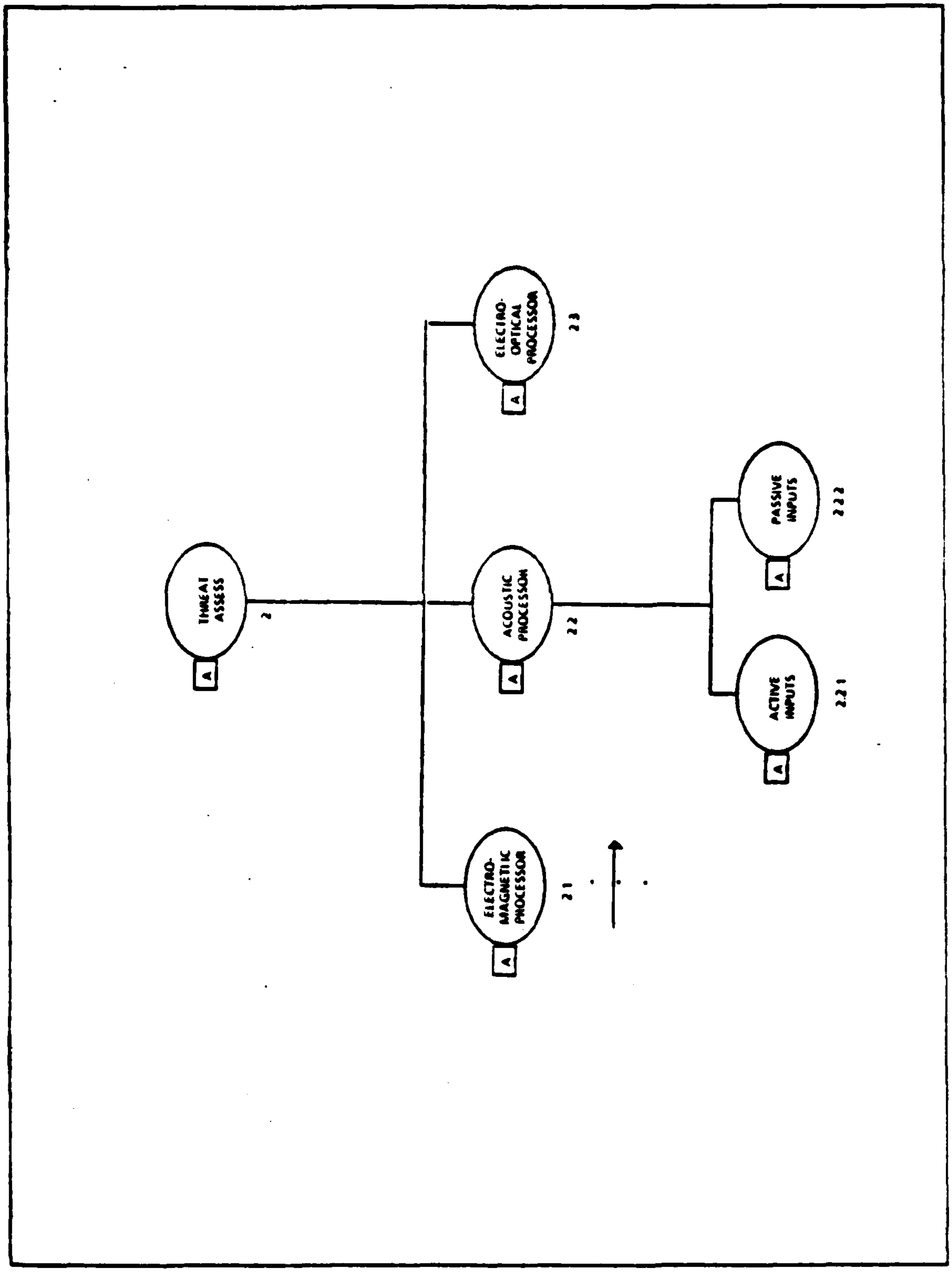


Figure 5.10 CTAS Level 2.

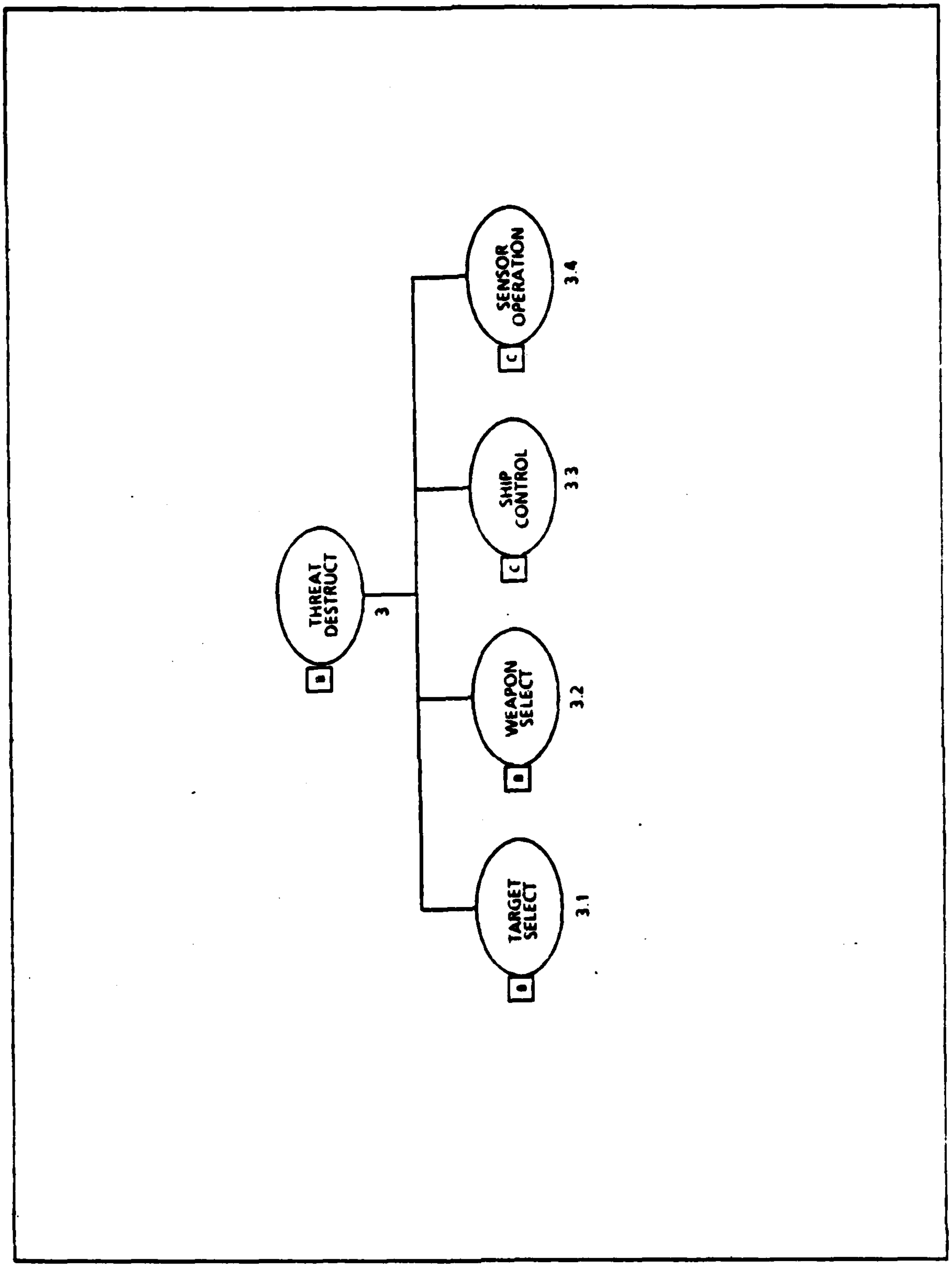


Figure 5.11 CTAS Level 3.

VI. CONCLUSIONS

A. TAO DECISION FUNCTIONS ARE COMPLEX

The position of Tactical Action Officer was initially created to provide quick reaction defense of Naval vessels until the Commanding Officer could arrive in CIC and assume the duties of fighting the ship. Since that time, the TAO's duties have evolved to managing whatever aspects of the tactical employment of his ship that the CO deems appropriate. In doing so, he must plan operations, identify and assess threats, and determine how best to continue an engagement once it commences.

The problems encountered in executing those TAO functions are many, varied and difficult. For example, the domain in which the Tactical Action Officer must function contains a wide range of stimuli to which he must respond. The body of possible responses to those stimuli is also immense even when constrained by rules of engagement which may be imposed. In assessing his options, the Tactical Action Officer must be familiar with a vast amount of knowledge and he also must be able to understand ill-structured problems.

The speed and sophistication of modern weapons decreases the time available for the TAO to assess data, recall information, reach decisions, and act upon those decisions. An anti-ship cruise missile traveling at Mach 1.8 covers 18 nautical miles in approximately 1 minute. In the time between launch and impact, an incoming missile must be detected, assessed as a threat, a countering weapon must be assigned, firing parameters must be entered, and the defensive weapon launched in order to intercept it. During the period before missile launch, the TAO must receive and interpret orders from higher authority, the status of ship systems, sensor indications and other data in determining his most appropriate course of action. In doing all this, questions of information overload and accuracy come into play.

Even with all these problems, the Tactical Action Officer is required to make correct and timely decisions in defending his ship and carrying out her mission. Computerized systems could resolve many of the problems addressed. Current computer technology is capable of solving several of these issues but is not capable of eliminating them all.

B. CURRENT TECHNOLOGY CANNOT ADDRESS ALL PROBLEMS

There currently exist systems in the fleet which are capable of assisting in the quick reaction defense of ships. Yet the author knows of no operational knowledge processing systems that can assist the TAO's decision process in tactically viable real-time.

Expert systems and database technology show some of the traits necessary to build a system such as CTAS which could address some of the issues raised in this paper. Yet, even though such systems may be able to provide decision assistance to the TAO, they still tend to be too slow for tactical applications. Expert systems can intelligently process knowledge but they require specific inputs which must be applied against a fixed set of rules. They have difficulty handling fuzzy or incomplete inputs or concepts.

Conventional computers are subject to catastrophic failure. Damage or degradation of one part of the computer may render the entire machine inoperable. Because of the probability of sustaining battle damage during an engagement, such an occurance could have significant impact on maintaining the combat capabilities of a ship.

Current technology also requires manual programming to update systems. This has the potential to result in long 'down' times to effect changes.

Even though current computer systems possess several characteristics required to effectively aid the tactical decision process, they fall short in many respects.

C. NEURAL NETWORKS HOLD PROMISE

Although still in their infancy, neural networks possess many characteristics which could be useful in building a computerized system to combine decision aids for the TAO into one entity and assist him in tactically acceptable real-time. Neural nets show strengths which could be useful in signal processors, threat detection systems, and knowledge processing.

The ability of neural nets to recognize patterns has direct application in acoustic, electromagnetic, and electro-optical signal processing [Ref. 15: p. 3]. They possess the ability to extract knowledge from seemingly unrelated masses of data which could provide significant benefit in the ability to receive signals through enemy countermeasures. Pattern recognition also gives neural nets unique knowledge processing capabilities in that they can achieve instantaneous nearest neighbor classification. They can function with fuzzy or incomplete inputs and have shown the ability to handle ill-structured problems. They also have the ability to recognize continuous speech and associative recall allows them to obtain the correct input data with incomplete or incorrect inputs. [Refs. 6,13: pp. 25.4]

Robustness is a significant plus concerning neural net systems. Nets have been observed to function with no decrease in effectiveness with up to 15% of neurons inoperable. As the number of inoperable neurons increases, the functions gradually degrade as opposed to catastrophic failure which occurs in conventional computers. [Ref. 6: p. 24]

Several neural net models also have the ability to learn or program themselves as they operate. Such an ability could allow systems to get smarter the more they are used. [Ref. 13: p. 4] Further, hybrids of existing models may even exhibit benefits not already observed.

The current state of neural network development does not suggest near term fruition of CTAS as envisioned, but development of sensor processors appears to be within the realm of imminent possibilities. Exploring the potential of neural nets could significantly aid in maintaining our assumed edge in tactical weapon systems. The author proposes that research be conducted to determine and implement tactical uses for neural networks.

LIST OF REFERENCES

1. OPNAVINST 3120.32B, Standard Organization and Regulations Manual, Office of the Chief of Naval Operations, Washington, D.C.

2. Pettit, CAPT Robert J., USN, "TAOs: To Fight the Ship", *US Naval Institute Proceedings*, pp. 55-61, February 1974.

3. Lehner, Paul E., et al, *Decision Aids for Battle Management*, Rome Air Defense Center, Griffiss AFB, New York, January 1983.

4. Bennett, John L., *Building Decision Support Systems*, Addison-Wesley Publishing Company, Reading, Massachusetts, 1983.

5. Zivovic, Streten, *Can Expert System Help Train Tactical Action Officers: Some Experiences From an Early Prototype*, Masters Thesis, Naval Postgraduate School, California, March 1986.

6. Kinoshita, June and Nicholas G. Palevsky, "Computing With Neural Networks", *High Technology*, pp. 24-31, May 1987.

7. Gostlow, Gareth A., *A TAO ASW Expert System Prototype*, Masters Thesis, Naval Postgraduate School, Monterey, California, September 1986.

8. Robinson, LCDR John G., USN, "A New Tack for Tacticians", *Surface Warfare Magazine*, pp. 24-30, November 1980.

9. Cox, Ingemar J., and Lewis J. Lloyd, *Artificial Intelligence Systems in Antisubmarine Warfare: Results of a Pilot Study With Expert Systems*, SACLANT ASW Research Centre Memorandum SM-176, SACLANTCEN, La Spezia, Italy, 15 December 1984.

10. Feigenbaum, Edward A., "Knowledge Engineering for the 1980's", Computer Science Department, Stanford University, 1982.

11. Fiegenbaum, E. A., and J. Feldman, *Computers and Thought*, Robert E. Krieger Publishing Company, Inc., 1981.

12. Harmon, Paul and David King, *Expert Systems : Artificial Intelligence in Business*, John Wiley and Sons, Inc., New York, 1985.

13. Rowe, Bruce, "New Computer Learns on the Job", *San Diego Business Journal*, March 9, 1987.

14. Rumelhart, David E., James L. McClelland and the PDP Research Group, *Parallel Distributed Processing. Explorations in the Microstructure of Cognition*, The MIT Press, Cambridge, Massachusetts, 1986.

15. Hecht-Nielsen Corporation, "Advanced Neurocomputer Applications Course", Hecht-Nielsen Neurocomputer Corporation, 1986.

16. Suplee, Curt, "Almost Human", *The Virginian-Pilot and Ledger-Star*, December 21, 1986.

17. Black, Norman, "Pursuit of the 'Paperless Ship' --- Admiral Aims to Clear Decks of Document Burden", *The Washington Post*, May 5, 1987.

18. Anderson, James A., "A Memory Storage Model Utilizing Spatial Correlation Functions", Department of Physics, University of California at Los Angeles, May 30, 1968.

INITIAL DISTRIBUTION LIST

		No. Copies
1.	Defense Technical Information Center Cameron Station Alexandria, VA 22304-6145	2
2.	Library, Code 0142 Naval Postgraduate School Monterey, CA 93943-5002	2
3.	Chief of Naval Operations Director, Information Systems (OP-945) Navy Department Washington, D.C. 20350-2000	1
4.	Professor Carl R. Jones Code 39 Naval Postgraduate School Monterey, CA 93943-5004	1
5.	Capt. Howard Venezia, USN Code 03 Director of Programs Naval Postgraduate School Monterey, CA 93943-5004	1
6.	LCDR Ronald W. Brinkley, USN USS SARATOGA (CV 60) FPO Miami, FL 34078-2746	1
7.	Mr. Waverly L. Brinkley 3419 Green Pine Lane Virginia Beach, VA 23452	1
8.	Capt. Bruce A. Whitehouse, USMC MCOTEA H and S Battalion MCDEC Quantico, VA 22134	1
9.	Ms. Susan Alderson Code 25 Naval Ocean Systems Center San Diego, CA	1

10. COMNAVINTCOM (OOJ) 1
4600 Silverhill Road
Washington, D.C. 20389-5000
Attn: LCDR Thomas Dove

END
12-87
DTIC